DETERMINATION OF PERCENT BODY FAT USING 3D WHOLE BODY LASER SCANNING: A PRELIMINARY INVESTIGATION

Todd N. Garlie*, John P. Obusek, and Brian Corner
US Army Natick Soldier Center
Natick, Massachusetts
01760

Edward J. Zambraski
US Army Institute of Environmental Medicine
Natick, Massachusetts
01760

ABSTRACT

The purpose of this study was to investigate the use of 3D whole body laser scanning technology to estimate body fat content. Percent body fat determined from current Army equations using manual and 3D laser scanning methods were compared to each other and to percent body fat obtained from Dual Energy X-ray Absorptiometry (DEXA), used here as a reference method. Manual measurements of body lengths and circumferences, 3D whole body laser scans and DEXA scans were performed on fifty-one men and women age 18-62. Mean percent body fat was not statistically different between the three methods. Correlation coefficients (R) were moderately high with low standard errors (SEE) and Lin's (1989, 2000) concordance analyses revealed moderate to strong measurement agreement between the three methods. This preliminary study demonstrates that the novel application of 3D whole body laser scanning to determine percent body fat is in close agreement with percent body fat determined using both Army manual measurements and DEXA.

1. INTRODUCTION

The quantification of body fat and muscle tissue is important for evaluating the health and physical performance capacity of an individual (Heymsfield et al., 2005; Nowicki et al., 2003; Robbins et al., 2003). For the Army, accurate assessment of body fat content is critical to sustain the health and performance capacity of warfighters (Marriott and Grumstrup-Scott, 1992). Several methods are available to researchers for the determination of body fat content that range from less technical approaches (e.g. standard anthropometric measurements input into regression equations) to highly technical and expensive approaches (e.g. magnetic resonance imaging) (Ellis, 2000; Heymsfield et al., 2005; Heyward and Wagner, 2004; Shephard, 1991). The Army currently uses manually obtained measurements of body lengths, circumferences and weight entered into gender specific predictive equations to estimate the percent body fat of an individual (AR 600-9, 1987). This method can be time consuming and prone to error when employed by less than highly trained personnel (Heymsfield et al., 2005). Whole body laser scanning is a relatively new technology that quickly produces a 3D digital model of the human form using low-power laser light and digital cameras (Douros et al., 1999; Lin et al., 2002; Tikuisis, 2001; Wells et al., 2000). Data extracted from this technology shows potential for accurately and rapidly estimating body fat content from body surface measurements without physically making contact with the subject.

The purpose of this study was to investigate the use of 3D whole-body laser scanning technology to estimate body fat content. Percent body fat determined from manual measurements and from 3D laser scanning and input into current Army predictive equations were compared to each other and to percent body fat obtained from Dual Energy X-ray Absorptiometry (DEXA), used here as a reference method.

2. METHODS

Thirty-seven (n=37) white male volunteers, aged 18-62 years and fourteen (n=14) white female volunteers, aged 25-51 years, participated in this study. Measurements for weight were taken to the nearest tenth of a kilogram. Measurements for body lengths and circumferences were taken to the nearest millimeter. All measurements were taken by a trained measurer. This study was conducted in accordance with provisions of the Army Regulation 70-25 and 45 CFR 46. All subjects were healthy and approved for participation by the Human Use Research Committee (HURC).

2.1 Body Fat Determination

Percent body fat was determined using manual anthropometry, 3D whole body laser scan, and DEXA scan to measure individuals during a one hour measurement session.

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Volunteers were first measured manually using a calibrated weight scale, anthropometer, and a steel tape measure to obtain height, weight and specific body circumferences as outlined in AR 600-9. These measurements were then entered into gender specific predictive equations to determine percent body fat (AR 600-9, 1987; Bathalon et al., 2004).

During the second procedure, individuals underwent a fifteen second scan using a Cyberware WB4 whole body laser scanner. Subjects wore spandex bike shorts (males), spandex bike shorts and sports tops (females), and nylon wig caps. The 3D models generated by the laser scanner were analyzed automatically using a custom software package created at Natick Soldier Center that generates anthropometric measurements analogous to the measurements defined in AR 600-9 for the body fat prediction equations. A small number of landmark location errors (<5%) were identified and corrected in the 3D generated anthropometric measurements (Listed as 3D automated and 3D corrected in Table 1 and Table 2). The corrected 3D measurements were used in the analysis. The digitally generated anthropometric measurements were then entered into the Army gender specific predictive equations to obtain percent body fat.

During the final portion of the measurement session, all subjects underwent a 6 minute whole body DEXA scan using a GE Lunar Prodigy DEXA scanner running software version 7.53. Percent body fat was calculated from the digitized DEXA scans using a proprietary 3-compartment method developed by the manufacturer and employed here as a reference standard.

2.2 Data Processing and Analysis

Statistical analyses were accomplished using STATA 9.0 (StataCorp, 2005). Student t-tests were used to compare mean percent body fat between the three body fat prediction methods. Regression analyses were used to test the linear relationships between percent body fat determined by manual measurements, 3D extracted measurements, and DEXA scans. Lin's concordance analysis was used to test how well the methods agree with each other (Lin, 1989, 2000). Statistical analyses were conducted separately for males and females due to the different variables required for input into the Army prediction equations. All graphs with 3D derived percent body fat use the 3D corrected values.

3. RESULTS

The mean and standard deviation of the required measurements for input into male and female Army prediction equations are shown in Table 1 and Table 2,

Table 1. Mean (and Standard Deviations) for Selected Anthropometric Variables Used for Male Army Prediction Equations (n=37).

	Manual	3D (Automated)	3D (Corrected)
Age	28.18 (12.6)		
Stature	1763.48 (62.4)	1750.90 (59.3)	1750.90 (59.3)
Weight	79.55 (9.6)		
Neck	388.59 (19.0)	399.39 (25.8)	395.06 (21.6)
Waist(Omp)*	878.70 (74.20)	886.65 (80.5)	888.34 (79.4)

*Waist(Omp) refers to waist circumference measured at omphalion.

Table 2. Mean (and Standard Deviations) for Selected Anthropometric Variables Used for Female Army Prediction Equations (n=14).

	Manual	3D (Automated)	3D (Corrected)
Age	37.07 (8.4)		
Stature	1628.71 (45.8)	1629.0 (42.6)	1624.85 (45.1)
Weight	56.65 (6.2)		
Neck	312.28 (15.4)	322.57 (18.8)	320.85 (13.9)
Waist(NI)*	694.85 (48.6)	719.37 (51.5)	718.31 (50.4)
Buttock	937.64 (55.4)	965.53 (57.9)	965.53 (57.9)
Forearm	234.5 (11.7)	239.35 (12.8)	239.35 (12.8)

*Waist(NI) refers to waist circumference measured at the natural indentation

Table 3. Mean (and Standard Deviations) of Percent Body Fat by Manual, 3D, and DEXA Predictions.

	Male (n=37)	Female (n=14)
Manual Body Measurements	18.5 (±3.8)	25.5 (±4.0)
3D Body Measurements	18.9 (±3.9)	23.8 (±3.9)
DEXA Measurements	18.9 (±4.7)	24.2 (±5.7)

respectively. On average, males in this sample were younger, taller, heavier, and had larger circumferences, when comparable, to females. On average, male percent body fat was lower than female percent body fat regardless of which method was used.

Mean percent body fat values and standard deviations determined from manual anthropometry, 3D scan data and DEXA scans are shown in Table 3. No statistical comparisons were conducted between males and females because of the different input variables required for the Army prediction equations. However, a Student's t-tests with Bonferroni corrections revealed no statistical differences when comparing percent body fat values determined from the three methods for males and females separately (*p*>0.05)(see Table 3).

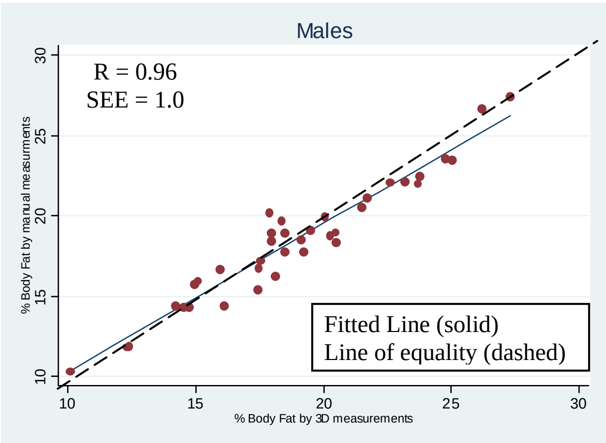

Fig. 1a. Correlation between percent body fat determined using manual measurements and 3D extracted measurements.

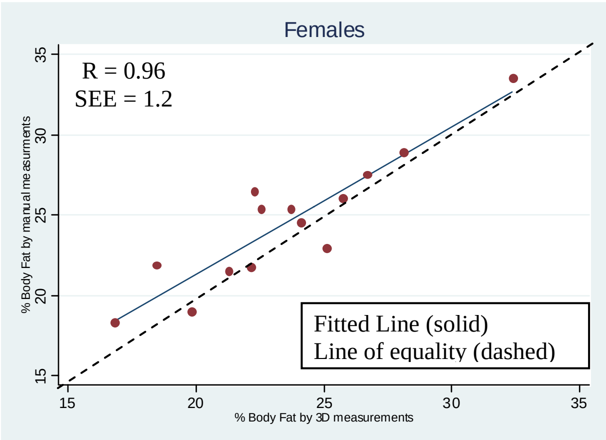

Fig. 1b. Correlation between percent body fat determined using manual measurements and 3D extracted measurements.

Figures 1a and 1b show the comparison of percent body fat estimates obtained from manual measurements of body lengths and circumferences outlined in AR 600-9 to those estimates obtained using analogous 3D generated body measurements for males and females in this study. A Linear regression analysis found large and statistically significant (*p*<0.05) Pearson correlation coefficients and small standard errors of the estimate (SEE) for males (r=0.96, SEE=1.0) and females (r=0.96, SEE=1.22) (see Fig. 1a and Fig. 1b, respectively). Lin's concordance analysis demonstrated strong and statistically significant (*p*<0.05) limits of agreement between the manual and 3D methods for determining percent body fat (*p*<0.05) (see Table 4).

Table 4. Concordance Test for Limits of Agreement and (Standard Errors) for Manual and 3D Extracted Percent Body Fat Methods Compared to DEXA.

	Male (n = 37)	Female (n = 14)
Manual Measurements vs. 3D Measurements	0.96 (0.013)*	0.94 (0.031)*
Manual Measurements vs. DEXA	0.78 (0.06)*	0.61 (0.16)*
3D Measurements vs. DEXA	0.74 (0.07)*	0.54 (0.18)*

**p* <0.05

Figures 2a and 2b show the comparison of percent body fat estimates obtained from DEXA scans compared to estimates derived from manual anthropometry for males and females in this study. Linear regression analysis revealed large and statistically significant (*p*<0.05) Pearson correlation coefficients and small

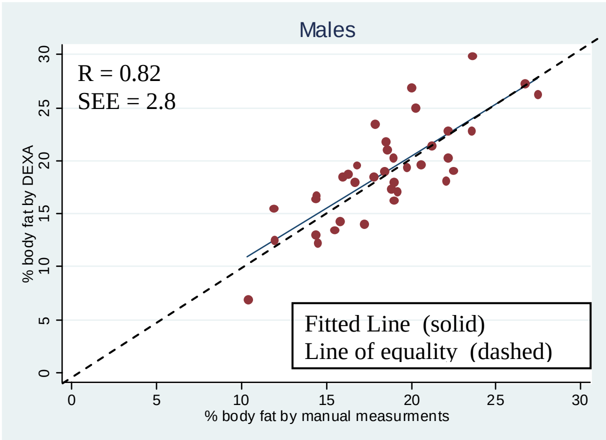

Fig. 2a. Correlation between percent body fat determined using DEXA and manual measurements.

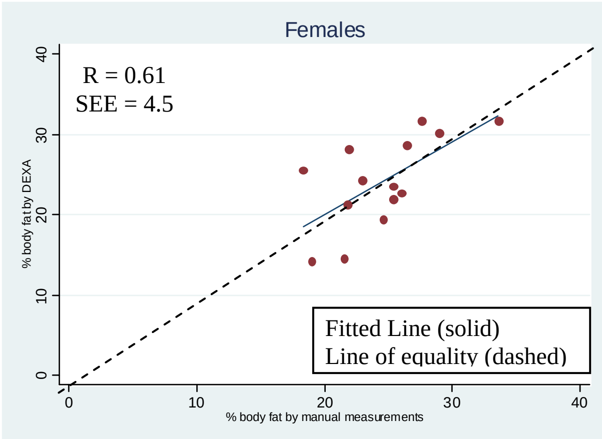

Fig. 2b. Correlation between percent body fat determined using DEXA and manual measurements.

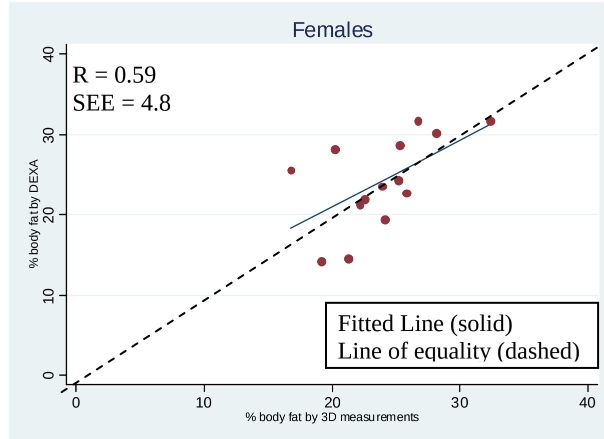

Fig. 3b. Correlation between percent body fat determined using DEXA and 3D extracted measurements.

standard errors (R=0.82, SEE=2.8) for males (see Fig. 2a). Linear regression analysis revealed moderate and statistically significant (p<0.05) Pearson correlation coefficients with larger standard errors (R=0.61, SEE=4.5) for females (see Fig. 2b). Lin's concordance analysis revealed statistically significant limits of agreement between the two methods (*p*<0.05)(see Table 4).

Figures 3a and 3b show the comparison of percent body fat estimates obtained from DEXA scans compared to estimates derived from 3D scans for males and females in this study. Linear regression analysis revealed moderate and statistically significant (*p*<0.05) Pearson correlation coefficients with moderate standard errors (R=0.74, SEE=3.3) for males (see Fig. 3a). Linear regression analysis revealed small but statistically significant (*p*=0.05) Pearson correlation coefficients and moderate standard errors (R=0.58, SEE=4.8) for females (see Fig. 3b). Lin's concordance analysis revealed statistically significant limits of agreement between the two methods (*p*<0.05)(see Table 4).

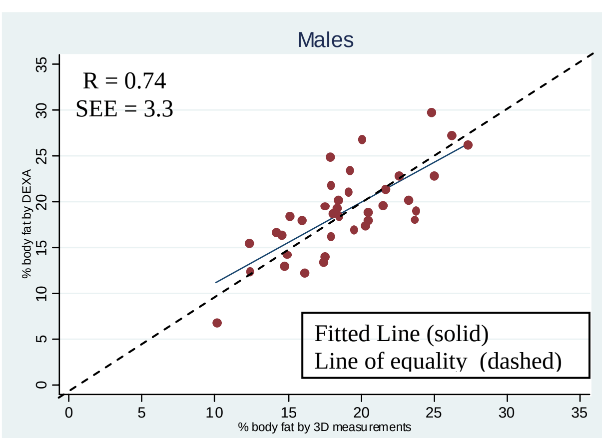

Fig. 3a. Correlation between percent body fat determined using DEXA and 3D extracted measurements.

4. DISCUSSION

The investigation of body composition (i.e. percent body fat and Lean Body Mass (LBM)) is critical for evaluating the health and physical performance capability of an individual (Katzmarzyk and Janssen, 2004; Marriott and Grumstrup-Scott, 1992; Nowicki et al., 2003; U.S. National Institute of Health [NIH], 1998). One of the primary goals of the military is to promote combat readiness and performance through nutrition, health, and fitness habits by increasing LBM and decreasing percent body fat (DoDi 1308.3, 2002; Friedl, 2004; Grumstrup-Scott, 1992).

Researchers investigating body composition have several methods available to assess total body and regional body composition with varying degrees of accuracy such as, underwater weighing, water or air displacement, electrical impedance or conductivity, skinfold measurements, circumferences, ultrasound, magnetic resonance imaging, soft tissue radiography, and computerized tomography. However, many of these methods require highly technical knowledge, are invasive, very costly to conduct, and have a high level of intra- and inter-rater variability (Ellis, 2000; Heymsfield et al., 2005; Heyward and Wagner, 2004; Roche, 1992; Shephard, 1991).

The application of novel 3D imaging in this study provides, for the first time, the ability to obtain potentially infinite body measurements in a very short amount of time (~15 seconds), while controlling for some of the variability often seen in the collection of manual anthropometric measurements. The goal of this study was to investigate the application of 3D whole body laser scanning technology to estimate percent body fat by extracting analogous 3D measures to those obtained manually for input into Army prediction equations. Percent body fat estimates from manual and 3D anthropometry were compared to each other and to DEXA estimates.

Males in this study, on average were taller, heavier, had larger body circumferences, and had smaller percent body fat estimates than females. These findings were not surprising because they mirror results found for the human population in general where males, on average, are larger, heavier (i.e. more muscle mass and larger bone structure) and have less percent body fat than females (Chumlea et al., 2002; Malina, 2005).

Although average percent body fat estimates were not statistically different within sex groups for the three prediction methods this did not test how well these prediction methods performed on individual estimates of percent body fat. Linear regression analyses were conducted to compare individual percent body fat estimates from manual measurements, 3D extracted measurements and DEXA. Lin's concordance analysis was also used to test how well the measurement methods agreed with each other (Lin, 1989, 2000). Linear regression results revealed moderate to strong and statistically significant Pearson correlations coefficients (R) and small to moderate standard errors (SEE) for both males and females in this study. Lin's concordance analysis showed moderate to strong and statistically significant measurement agreement between all three methods. A review of body composition literature comparing percent body fat using one of several prediction equations and standardized methods revealed a large range of correlation coefficients and standard errors (Heymsfield et al., 2005; Heyward et al., 2004). A direct comparison of percent body fat results between studies is therefore very difficult to achieve. For this study, the primary comparative sources come from the original development of military body fat equations conducted during the last two decades of the twentieth century (Hodgdon and Beckett, 1984a, 1984b; Vogel et al., 1988; and Wright et al., 1980, 1981). Results from these studies using underwater weighing as a reference standard found correlation coefficients and standard errors ranging from ($R=0.79$, $SEE=3.9$ to $R=0.90$, $SEE = 3.5$) for males and ($R=0.73$, $SEE=4.1$ to $R=0.85$, $SEE=4.1$) for females. Correlation coefficients and standard errors from this study overlap with these earlier studies and in some cases have smaller standard errors. This suggests that the application of 3D imaging to predict percent body fat by using current Army equations has significant potential and should be explored in greater detail. The placement of this technology in Military Entrance Processing Stations (MEPS) for example, has the potential for obtaining anthropometric body measurements for the determination of clothing and equipment size and fit and body fat on all recruits simultaneously. This could provide important ground work for developing a large scale epidemiological database to follow changes in body composition and health during the Army career of these recruits.

The application of 3D imaging to predict percent body fat using current Army equations shows promise for the military. There were, however, limitations to this study. One of the main limitations was the size and composition of the sample. Due to the location of the study the sample was limited to a fairly uniform population consisting primarily of young white male and female military personnel or slightly older white male and female civilian personnel. The effect of this sample composition is apparent, especially among females in this sample, where the relationship between the measurement methods was less clear. This is reflected in the weaker correlation coefficients and larger standard errors. An increase in sample size would benefit the analysis for this group. Another limitation in this study was the comparison of percent body fat using current Army prediction equations compared to DEXA, used here as the reference method. The prediction equations used in this study were originally derived by the military using underwater weighing as a standard reference method. Therefore, some of the variability found when comparing percent body fat derived by these Army equations after 3D data extraction to DEXA estimates of percent body fat can be accounted for because DEXA uses different proprietary algorithms for deriving percent body fat. Lastly, some variability in the data can be accounted for by software data extraction problems from 3D scans. In this study we found that there were some instances that the automatic extraction algorithms used to extract 3D measurements would misidentify an anthropometric landmark resulting in a measurement error. A manual exploration of the 3D scan images did locate these errors. Continued efforts are underway to enable the 3D scan algorithms to better extract specific landmarks automatically.

5. SUMMARY

This preliminary study demonstrates that the novel application of 3D whole body laser scanning to determine percent body fat is in close agreement with percent body fat determined using both Army manual measurements and DEXA.

The clear advantages of 3D scanning over manual methods are that it is rapid, it eliminates the need for direct physical contact during measurement, and it may reduce error in comparison to manually derived measurements. Furthermore, 3D scanning provides the capability of extracting nearly an infinite number of data points from the digital models to investigate body composition beyond body fat content by looking at, for example, volumetric measures, surface areas, and adipose topography, predictors that would not be possible using current manual methods.

Current applications of 3D laser scanning technology in the Army have centered on equipment interactions with the human form for design and equipment sizing purposes. As the technology becomes more widespread for these applications, this study reveals 3D laser scanning can provide the capability to assess body composition quickly, accurately, and repeatedly over time in order to monitor and maintain a healthy force. Additional research is necessary to refine the automated measurement extraction algorithms and to investigate this application across a more diverse population that includes individuals from a larger range of body shapes, sizes, and ethnic groups.

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